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Iowa State University Capstones, Theses and Dissertations

Spring 2018

Variation in Maize Hybrid Germplasm Performance following a Winter Rye Cover Crop

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Variation in Maize Hybrid Germplasm Performance following a Winter Rye Cover Crop

by

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A creative component submitted to the graduate faculty

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Agronomy

Program of Study Committee:

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Iowa State University

Ames, Iowa

2018

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Introduction

Cover crop introgression into conventional corn and soybean rotational systems is a practice employed by some farmers in today's upper Midwest farming landscape. The most utilized cover crop species in the state of Iowa has been winter cereals, specifically winter rye (*Secale cereale* L.) (Miguez, 2016). These winter rye cover cropping systems provide new logistical and plant disease challenges that farmers must address if cover crop usage is going to continue to expand in the future. Cover crops provide benefits, including soil health improvements, erosion prevention, weed suppression and reduction in nitrate leakage (Lal, 1991). However, two of the main factors slowing the adaptation of rye cover cropping systems are the reported yield reductions in corn produced following a winter rye cover crop (Acharya et al., 2017) and time constraints for spring planting of corn (Johnson, 1998). Both of these factors can add significant investments to farmers that require system assessments to ensure a winter rye cover crop is a justifiable change to their cropping operations.

The exact mechanisms that cause yield reductions of corn following a winter rye cover crop are not completely known but there is research into multiple factors that could contribute. Allelopathy occurs when chemicals released by one plant species inhibit the growth of another adjacent and different plant species (Johnson, 1998). Winter rye does release allelochemicals which have inhibitory effects on certain weeds under specific environmental conditions (Olofsdotter, 2002). These effects cannot be discounted as a possible factor in yield reduction in corn, however, specific research on this with corn and winter rye has been inconclusive. Other factors such as changes in soil conditions due to winter rye mulch also could be a contributing factor. Seed growth microenvironments could be less favorable due to changes in soil temperature or decaying biomass from the rye could tie up soil nitrogen (Huber, 1986). A third potential factor is increased pathogen presence, which may contribute to yield decline. Research has shown that a winter rye cover crop could form a "green bridge" that allows soil fungal pathogens to overwinter or have a greater persistence within the soil (Bakker et al., 2016). Soil fungal pathogens such as *Fusarium* sp. and *Pythium* sp., when shown to be in greater numbers at seed germination, can have an adverse effect under certain environmental conditions (Acharya et al., 2017). These environmental conditions usually are those that are within the range for most favorable growth of the pathogen and are not the most favorable for growth of the crop or host plant.

All of these factors contribute to the current recommendations of waiting seven to ten days, or longer, after winter rye cover crop termination before planting a corn crop (Raimbault, 1991). This waiting period was shown to decrease the chances of the above factors having a significant decrease on corn yields (Raimbault, 1991). However, this seven to ten waiting period can be problematic for farmers as they adjust their farming systems to include a winter rye cover crop. Weather, herbicide effectiveness and application, spring tillage and nutrient additions all require accurate timing to produce high yields. This waiting period reduces the flexibility farmers require and can have a detrimental effect on crop yields and profitability in certain instances.

Maize is a very diverse crop that has over 300 races and has been adapted to climates all over the world (Troyer, 1999). This ability to adapt, and multiple cultivars, makes it very possible that certain varieties may have the ability to tolerate the factors that can cause yield loss from a winter rye cover crop. However much of this biodiversity has been lost within the corn hybrids that are grown in the upper Midwest and the U.S. Corn Belt region (Troyer, 1999). Yellow dent corn is a very prolific and the most productive race of corn that has been developed in the world to date. This race of corn was developed in North America in the 1800's with a cross of two distinct corn races, Northeastern Flints and Virginia Gourdseed (Brown, 1985). These varieties, through repeated crossing and selection, formed the basis for maize yellow dent inbreds. Five widely adapted, century-old, open-pollinated cultivars account for 87% of the known background of today's U.S. hybrid corn (Troyer, 2004). This very narrow genetic diversity is the genetic base for most of the U.S corn industry.

The main objective of this study was to determine if genetics from a diverse maize portfolio could show tolerance, expressed as lack of yield reduction, when planting corn followed by an immediate glyphosate termination of a winter rye cover crop. A secondary objective was to determine what physical characteristics changed within the hybrids or grain when following the winter rye cover crop. The experiment was designed to maximize potential stress to these hybrids following winter rye cover crop termination. This stress potential will mimic the environment that causes farmer concerns of not waiting to plant corn directly following termination.

Image 1. Experimental Rye growth at Neely Kinyon Site

Photo courtesy of Michael Witt, 2018

Materials and Methods

Experimental Design

This experiment was a completely randomized design. The design was selected to facilitate planting and allow comparison of the presence and absence of a winter rye cover crop across twelve experimental corn hybrids. The two blocks were split with or without the winter rye cover crop and each block contained three randomized repeated measures of all hybrids within the study. Entries were randomly placed into the experimental plot layout utilizing a random number generation function in Excel (Microsoft Corp., Redmond, WA). The individual plots were twenty feet long and four rows wide at a planted population of 32,000 seed per acre. The dimensions of the experiments were eleven ranges long and fourteen plots wide at the Castana location (Table A1) and twelve ranges long and fourteen plots wide at the Neely Kinyon location (Table A2). Each experimental block was surrounded by a commercial corn hybrid to prevent interference from border and field edge effects.

Twelve corn hybrids were evaluated for this experiment (Table A3). Seed for these hybrids were produced at one field site near Ames, Iowa in the summer of 2016 using conventional hand pollination techniques. The hybrids were created from a diverse collection of temperate and tropical inbreds, including some commercial and experimental inbreds, from several breeding programs. This allowed for a larger diversity of biotype and promoted genetic diversity while maintaining viable yield potential. These lines were from multiple sources within Iowa State University, USDA-ARS, the Germplasm Enhancement of Maize project and other public entities. Some of these inbreds ranged from 50% to 100% tropical germplasm origins. Yield potential for these hybrids was variable given the diverse nature of the data set. The range of maturities within this germplasm set is between 105 and 115 days to maturity. No genetically modified herbicide or insect traits were present within these inbreds or hybrids to remove possible trait effects. Fungicide and bactericide seed treatments were not applied to seed to allow better expression of potential root diseases and eliminate possible bias to results from other seed treatment advantages.

Field Parameters

The field experiment was conducted at two Iowa State University Research Farm Locations during the 2016-2017 growing seasons. The individual sites were selected to provide diverse soil and meteorological conditions while still providing appropriate corn production environments. There was a single soil series within each experimental area.

The first location was the Western Research Farm located near Castana, Iowa (42.3.38.92N, 95.49.57.66W). The soil type within the experimental boundaries was a Monona silt loam (9-14% slope; Fine-silty, mixed, superactive, mesic Typic Hapludolls) (NCSS, 2016). This location had a Crop Suitability Ratings (CSR2) of 60/100 (Burras et al., 2015).

Image 2. Western Iowa Research Farm Site, Castana Iowa (NRCS Web Soil Survey)

Photo courtesy of NRCS Web Soil Survey, 2018

The second location was the Neely-Kinyon Research Farm located near Greenfield, Iowa (41.16.47.16N, 94.26.51.96W). The experimental area consisted of Macksburg silty clay loam (2-5% Slope; Fine, smectitic, mesic Aquertic Argiudolls) (NRCS, 2017). This location had a Crop Suitability Rating (CSR2) of 86/100 (Burras et al., 2015).

Image 3. Neely Kinyon Research Farm Site, Greenfield IA (NRCS Web Soil Survey)

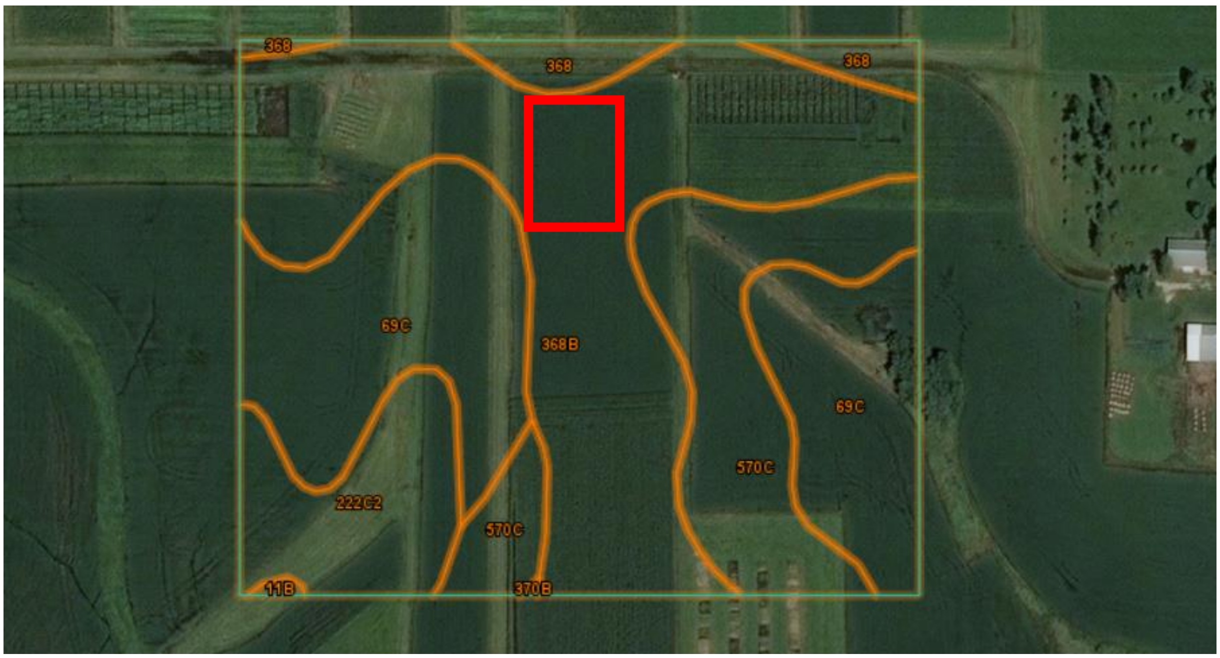


Photo courtesy of NRCS Web Soil Survey, 2018

Both locations were seeded with Elbon winter rye in the fall of 2016 in accordance with the experimental design. The winter rye seed were procured from the Green Cover Seed company, Lot# E4-2nd 15.1. Both locations had soybean as the previous crop. The planting for the winter rye at Castana was performed by a model 9300 drill (John Deere, Moline, IL) at one bu/acre on 10 November 2016. Winter rye at the Neely Kinyon location was seeded with a Great Plains Solid Stand no-till drill at one bu/acre on 9 November 2016. The winter rye seed source had a PLS rate of 90 with germination at 92% and a seeding rate of 1.26 million PLS/acre at both locations. Tillage was not done the previous fall or spring at either site before planting corn in the spring of 2017.

Soil samples taken from the experimental areas the previous fall showed that the available P and K concentrations were within the optimum range (16–20 mg kg^{-1} Mehlich-3 P; 86–120 mg kg^{-1} Mehlich-3 K) at both locations and no fertilizers additions were required. Nitrogen fertilizer was not applied to the growing cover crop before corn planting at either location. Following corn planting, each location received 150 lbs N per acre as 32% UAN liquid. At the Castana location, N fertilization was done two days after planting corn while the Neely Kinyon location received the UAN six days after planting.

The experimental corn at both locations was planted with an ALMACO cone style planter (ALMACO Co., Nevada, IA) at 36 seeds per 20-foot plot, or approximately a 32,000 seeds per acre population. The planting dates were 12 May 2017 for the Castana location and 5 May 2017 for Neely Kinyon. Seed at both locations were planted at a depth of one to one and a half inches.

In order to ensure maximum potential effect of winter rye on corn, cover crop termination occurred on the day of planting at the Neely-Kinyon site and one day prior to planting at the Castana site (Acharya et al., 2017). The termination method was by glyphosate application at both locations. The height of the winter rye cover crop at both locations was 18-21 inches. The weed control program for the Castana location consisted of a single application of glyphosate herbicide at 32 oz. per acre of Round-up (Monsanto Co. St. Louis Mo.) on 11 May 2017 and manual weeding throughout the remainder of the growing season as needed. This glyphosate application was used across both treatments to terminate the winter rye cover crop and any weeds emerged prior to planting of experimental corn. The weed control program for the Neely-Kinyon location consisted of multiple herbicide applications. All plot areas received an application of glyphosate Round-up herbicide (Monsanto Co. St. Louis Mo.) at 42 oz. per acre to terminate the winter rye cover crop and any emerged weeds on 5 May 2017. A second herbicide application of Status (BASF Ludwigshafen, Germany) at 7 oz per ac with ammonium sulfate at 8 oz per acre and methylated seed oil at 1.5 qt. per acre was applied on 20 June 2017.

Image 4. Rye at Termination at Neely Kinyon Site

Photo courtesy of Michael Witt, 2018

Image 5. Rye at Termination at Castana Site

Photo courtesy of Michael Witt, 2018

In-season data collection was done to document hybrid growth and developmental timing throughout the life cycle. Data collected from each plot included plant final stand counts, hybrid pollen shed timing, hybrid silking timing, plant height, and ear height. The traits of pollen shed and silking were reported based on growing degree days. All weather data were collected at nearby recording weather stations (Iowa Environmental Mesonet, 2018). Each location had a recording weather station located within a 1/4 mile of the plots. The weather station IA1277 services the Iowa State University Western Research Farm near Castana, IA while IA3438 is located at the Neely Kinyon Research farm by Greenfield, IA. Growing degree days (GDD) were calculated from planting thru harvest season for each location. The formula for calculation of corn GDD follows:

Formula 1: Calculation of Corn Growing Degree Days

GDD = (Daily Maximum Air Temperature + Daily Minimum Temperature)/2 – 50.

Parameters: If maximum air temperature is greater than 86°F, Value is set at 86°

If minimum air temperature is less than 50°F, Value is set at 50°

The weather traits of air temperature, precipitation and GDD’s were utilized to look for yield effecting reactions to the winter rye cover crop management practices.

Corn grain harvest was done by hand at each location. The following day, processing of hybrid entries from each of these sites was done. The harvest date for the Castana location was November 2, 2017 with a total GDD of 3059 for the season (Table A4). The harvest date for the Neely Kinyon location was November 7, 2017 with a total GDD of 3281(Table A4). Ears were harvested from the middle two rows of each 4-row plot to avoid border effects, and then taken to a laboratory for yield determination. There was no artificial drying performed on these samples. The measurements recorded in the laboratory were grain plot weight, grain kernel moisture, test weight and the number of ears per plot. The harvested plot area was 2/1000th of an acre at 17.5 ft harvested plot length at 30 inch row spacing. Kernels were removed from ears with a John Deere 1-B motorized bulk corn sheller. The plot weight was captured by a GSE 350 with S-Cell hanging scale calibrated to 0.01 lbs. Moisture and test weight was determined by a handheld Mini-GAC (Dickey-John Corp., Auburn, IL) at time of grain processing. The formulas utilized for calculating the yield measurements are listed below.

Image 7. John Deere 1-B motorized bulk corn sheller

Photo courtesy of Michael Witt, 2018

Formula 2: Bushels per Acre for each Hybrid

Bushels/acre = (Harvested dry matter lbs) ÷ Standard lbs/bushel ÷ plot area acres

Formula 3: Calculation of Harvested Dry Matter

Harvested Dry matter (lbs) = [(100 – measured % moisture) × 0.01)] × [total harvest weight]

Formula 4: Calculation of standard lbs/Bushel

Standard lbs/Bu = [(100 – standard % moisture) × 0.01] × standard bushel weight (lbs)

$$47.32 = [(100\text{-}15.5) \times 0.01] \times 56$$

The standard bushel weight of corn is 56 lbs/bushel. Corn has a 15.5% moisture when a bushel of corn weighs 56 pounds.

Formula 5: Calculation of Plot Area

Plot Area acres = (harvested plot width ft) × (harvested plot length ft) / (43560 ft2/acre)

A grain sample from each plot was analyzed for kernel moisture, protein, starch, oil concentrations, and density by a calibrated near infrared spectrometer (Foss Infratec 1241 Grain Analyzer, Foss Inc, Denmark). These results are reported on a 100 % dry matter basis.

Data were analyzed using JMP Pro 13 software for a completely randomized design with SAS v.13 (SAS, 2016). The model utilized location, cover crop, and corn hybrids as fixed effects and was normalized for stand count to adjust for variance (Table A6). Graphical and numerical analyses were performed following significant F-tests and mean separations at $P<0.05$.

There were three sets of variables measured. Phenotypic traits of plant harvest population, corn 50% pollen shed and 50% silking time and plant and ear height were measured. The harvest variables were grain moisture and calculated yield at bushels per acre. Grain quality traits determined by NIRS were moisture (reported at 0%), starch content, oil content, kernel density and kernel protein content. The means of all of these parameters were calculated first on a basis of hybrid × location × management style. Population at harvest was used as a fixed factor in the model. This was done due to the variability of this trait and allowed for it to better reduce error in other measurements (Table A10). The means of the remaining traits were then input into the model for analysis. When F-tests were significant, mean separations were calculated utilizing the Student T method with significance reported at the 0.05 level of probability.

Results

Within the 2017 growing season, disease or insect damage were never evident factors that might have influenced yield. Overall the weather variables of air temperature, precipitation and GDD's deviated very little from the historical trends for both locations (Graph A1, A2, A4, A5). The historical trends were from 1951-2016 for all weather data. There were fluctuations in the timing of rain for both locations within the growing season, with precipitation being below long-term normal in June and July (Graph A3, A6). Precipitation was 5.8 inches above normal at Castana for August thru October (Graph A3, A6) with a similar trend at Neely Kinyon (Graph A3) of 6.3 inches above normal for that timeframe. The full growing season rainfall totals for the Castana and Neely Kinyon location were above the long-term average. The Castana location had a long term average of 23.1 inches of rain compared to the 2017 amount of 26.3 inches for a difference of 3.2 inch increase in precipitation for the growing season (Table A4). The Neely Kinyon location had a long term average of 25.1 inches of rain compared to the 2017 amount of 27.4 inches for a difference of 2.3 inch increase in precipitation for the growing season (Table A4).

Eleven different traits were evaluated in this study across twelve hybrids developed from distinctly different germplasm bases. Significant hybrid differences were observed for all traits recorded. Cover crop treatment also influenced corn response, but the corn hybrid × cover crop interaction was not significant for any traits measured (Tables A7, A8, A9). Traits are presented within the three categories of corn development, corn harvest measurements, and grain quality characteristics.

The corn development traits collected for this experiment were corn flowering time, stature and population (Table A8). Corn flowering time was measured by GDD from time of planting until 50% of pollen shed and 50% plant silking. Hybrids following the winter rye cover crop required more GDD to reach 50% pollen shed and 50% silking compared to corn that did not follow a winter rye cover crop. Plant and ear height differed significantly for hybrid. However, the influence of winter rye cover crop treatment did not influence either plant height or ear height (Table A8).

The harvest traits collected were grain yield, reported in bushels per acre at 15% moisture, and grain moisture percentage at harvest. Both of these traits showed very interesting results but for different reasons. Grain yield differed for hybrid but not for cover crop (Table A9). This would state that there is no difference between the yields of hybrids in a winter rye cover crop system with almost same day planting termination compared to a no-winter rye cover crop system (Table A9). The moisture percentage for grain at harvest showed a significant difference between hybrids as well as presence or absence of winter rye cover crop (Table A9). Eleven out of twelve hybrids showed a statically significant increase in moisture content at harvest when following the winter rye cover crop compared to no cover crop (Table A9). These changes ranged from -0.4 to 1.3 percentages different for specific hybrids. Similar results of increased moisture are present in the grain quality traits as well.

The grain quality traits of kernel density, starch, oil, and protein concentrations, and moisture percentage did not all show analogous responses or results. The concentrations of kernel moisture, protein, and starch, and kernel density differed for hybrid and cover crop (Table A7). The trait of kernel oil concentration was significant for the different hybrids but not for the management practice of winter rye cover crop versus no cover crop (Table A7). The four grain quality traits did not all respond the same way when following the winter rye cover crop. Grain moisture was greater for eleven of twelve hybrids at harvest when hybrids followed a winter rye cover crop compared to no cover crop (Table A7). Protein concentration was lower for ten of twelve hybrids when corn followed the winter rye cover crop (Table A7). Starch concentration and kernel density were greater when corn followed a winter rye cover crop (Table A7).

Discussion

The results of this study show that there are statistical differences between hybrids in a winter rye cover crop system compared to no cover crop for certain traits. Within seven of the eleven traits studied there were differences in hybrid performance. There were also differences between all of the hybrids within this study across all traits. This was not unexpected given the diversity of germplasm and maturity groups. This study did not show that there was a statically significant interaction between the hybrids and the management. Numerically there was wide variation in hybrid responses between the presence and absence of the winter rye cover crop in relation to yield. Perhaps additional site years of study with a greater number of hybrids would provide better precision.

There were a few interesting observations within these traits to note. The first is that the moisture tested by the harvest traits and the grain quality NIR measurements showed that the grain was significantly wetter at harvest following the winter rye cover crop. Multiple data collection methods validating the same resulting trend is a benefit. Another trait of interest was the phenotypic flowering time. Across all hybrids tested there was a delay in both pollen shed and plant silking time. This shows that there is a significant change occurring to the plants based on the management system independent of the hybrids and environment as it occurred at both locations.

Both of these traits in conjunction display that there is a delay in corn maturation throughout the growing season due to the winter rye cover crop in this experiment. There have been studies that show the delay in maturity is significant at V2-V5 growth stage (Acharya et al., 2017) at the same rye termination timing as this experiment. The initial start time of this delay is not known from this study as there were no emergence traits taken to see if the winter rye cover crop. Stand counts were taken, however, there was not a difference for stand density between winter rye cover crop and no-cover crop control treatments. The reasons for this developmental delay could be caused by a few different factors, but it is not entirely clear. Winter rye has been shown to tie up soil nutrients or the reduce water availability for corn which can lead to delayed growth (Kaspar, 2011). Corn seedling pathogens overwintering ability may increase due to the presence of a winter rye cover crop (Smiley et al., 1992). This increase in corn seedling pathogens, such as *Fusarium* spp. and *Pythium* spp., may be using the winter rye cover crop as a "green bridge" for this overwintering process to increase pathogen populations (Smiley et al., 1992). These factors could result in a delay in corn development throughout the growing season but are not fully explained. This study did not show significant yield losses associated with this maturity delay as in other studies (Acharya et al., 2017) for the same winter rye termination timing.

The change in development patterns for these hybrids also is responsible for the change in grain quality traits observed. The changes in harvested kernel moisture, protein, starch and density with regards to the winter rye cover crop lend themselves to further review. This study indicates significant changes of the grain quality traits from hybrids based solely on a winter rye cover crop. Kernel starch concentration in this study is particularly interesting. Starch levels in the corn can decrease due to stress and increase in non-stress conditions during kernel development stages (Abendroth, 2011). This study showed a significant increase in starch content with the use of a winter rye cover crop. This would indicate that there was no adverse effect of the winter rye cover crop late in the season that influenced starch accumulation.

To confirm these results, studies with more replication and data years are needed. This study was conducted in two distinct environments and soil types in Iowa in a single growing season. The expansion of more testing sites and data points will help to increase validity in this study. Another factor of the experimental design that could be improved to enhance statistical power would be using a randomized complete block design instead of the completely randomized design used. This would provide for greater replication and degrees of freedom in error terms, allowing for greater power in the analysis of variance.

Conclusions

The objective of this study was to determine if diverse corn hybrids might show tolerance to yield reduction when following a winter rye cover crop. Results did not show a statistically significant interaction between the hybrids and the cover crop. This means that it cannot be determined, by this study, that a winter rye cover crop management system can either improve or decrease individual hybrid performance in comparison to other hybrids in the study. This was true across all eleven observed traits including yield.

Overall this study demonstrated that certain phenotypic, harvest and grain quality traits can be affected by planting hybrids into a winter rye cover crop. In this study, grain yield was not significantly changed, but the traits affecting yield, and which have great economic importance, such as kernel moisture and plant morphology, were influenced by the winter rye cover crop. Results also document that by planting corn hybrids into a winter rye cover crop, there is the potential to change the quality of the grain produced. These findings require more research to corroborate the potentials described for corn planted in a winter rye cover cropping system.

Appendix

Table A1. Field Plot Layout: Castana Location 2017

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
11															11
10			7	9	1	8			9	12	6	7			10
9			2	5	11	12			11	9	3	2			9
8			4	3	6	4			8	4	5	12			8
7			10	8	12	11			1	10	4	11			7
6			3	6	2	4			2	4	6	10			6
5			5	11	3	5			1	3	5	8			5
4			1	8	2	7			6	7	9	5			4
3			6	9	10	9			12	3	11	10			3
2			12	10	7	1			1	7	2	8			2
1															1
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	

Buffer

Cover Crop: RM 1, RM 2, RM 3

No Cover Crop: RM 1, RM 2, RM3

RM: Repeated Measure

Table A2. Field Plot Layout: Neely-Kinyon Location 2017

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
13																	13
12																	12
11			5	4	6	10				7	4	12	6				11
10			7	1	11	2				5	10	9	8				10
9			4	12	8	10				6	11	12	2				9
8			9	3	8	2				1	7	7	2				8
7			5	1	5	2				6	8	9	11				7
6			8	10	9	7				1	1	3	8				6
5			11	7	12	11				5	10	5	3				5
4			6	3	4	9				10	3	4	2				4
3			3	12	1	6				4	9	12	11				3
2																	2
1																	1
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	

Buffer

Cover Crop: RM 1, RM 2, RM 3

No Cover Crop: RM 1, RM 2, RM 3

RM: Repeated Measure

Table A3. Experimental Hybrids

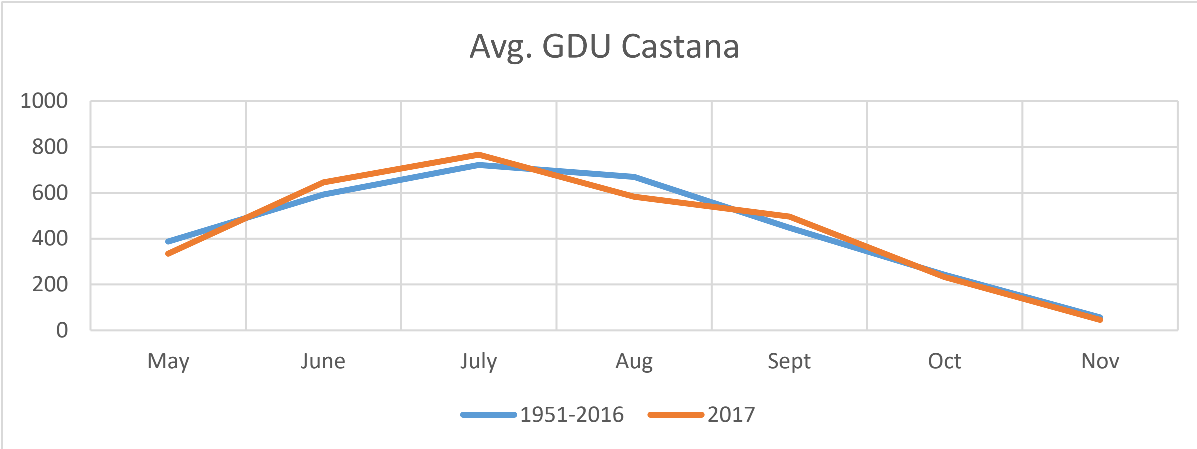
Hybrid Entry	Female parent	Male parent	Progeny Hybrid Pedigree
1	Commercial Pedigree 1	BS11HMC6	CP1/Bulk: BS11HM C6 selections: 5,11,12,24,32:8081)-01-01-01-01-04-02-02]12
2	Commercial Pedigree 2	BS31(R)C0	CP2/BS31(R)C0-246-1-01-01-01-01-B-B-B-B-B-B-B]02
3	Commercial Pedigree 2	AR17056:S1217	CP2/AR17056:S1217-B-025-B]04
4	NS1:S0852	B95/B99	NS1:S0852-B-054-B-B)-01///B95/B99)-B-012-001/2/B97/B99)-B-029-001]7)-02-03-03-01-01-01-B]12
5	CUBA164:S2012	BSKRL	(CUBA164:S2012-459-001-B/GEMS-0002)-B-B-031-B-B-B-02//BSKRL2(HI)C2-054-02-01-01-01-01-B]11
6	CHIS740	BS21	CHIS740:S(PHW17)(87916W)-126-001-B/BS21(R)C8:241-241-01-02-03-01-01-B-B]08
7	AR16021	SCR01:N1310R1	AR16021:S0908a-039-001-B-B-SIB-B)-01/SCRO1:N1310R1 R1)%B BBK:3343-09-01-01-02-01-02]11
8	Commercial Pedigree 3	53SS4/GEMS0026	CP3//(53SS4/GEMS-0026)-SIB-B-003-B]06
9	BR52051	BARBGP2	BR52051:S172641-B-018-B/BARBGP2:N08a12 R1)%B BBK:3373-21-01-01-03-02-01]06
10	OH623:437	DKXL370	OH 623:4371)-01/DKXL370:N11a20-234-002-B-B-B-Sib-B)-04]06
11	AR16035	B97/B95	AR16035:S02-615-001-B wx//B97/B95)-069-1-1-1-1-2-2-01-01-B-B-B-B]12
12	Commercial Pedigree 3	LMPPR0	CP3/LMPPRO(B)Syn1-16-02-B-03]03

Table A4. Weather Data- Western Research Farm

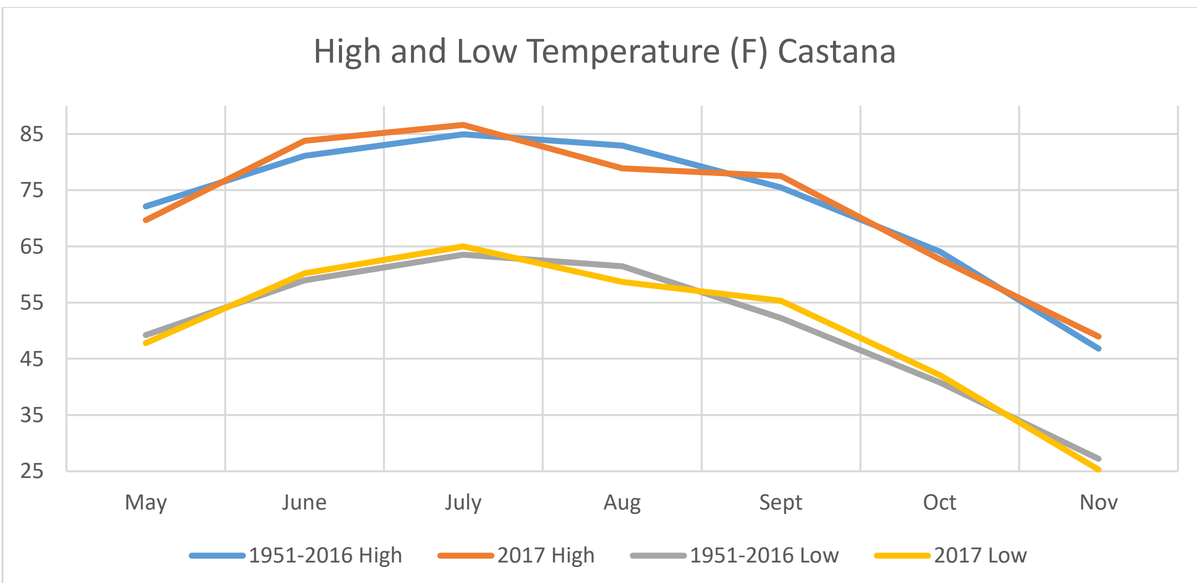
Castana

	Time	Avg. Total GDD	Avg. High (F)	Avg. Low (F)	Rainfall (in.)
May	1951-2016	387.5	72.1	49.2	4.4
	2017	335.0	69.7	47.8	6.9
	Diff	-52.5	-2.4	-1.4	2.5
June	1951-2016	592.0	81.1	59.0	4.7
	2017	646.0	83.8	60.2	3.0
	Diff	54.0	2.7	1.3	-1.7
July	1951-2016	721.1	84.9	63.5	3.8
	2017	766.0	86.6	65.0	1.2
	Diff	44.9	1.7	1.5	-2.6
Aug	1951-2016	669.7	82.9	61.5	3.9
	2017	582.0	78.9	58.7	6.1
	Diff	-87.7	-4.1	-2.8	2.3
Sept.	1951-2016	447.0	75.5	52.2	3.1
	2017	496.0	77.5	55.3	3.5
	Diff	49.0	2.1	3.1	0.4
Oct.	1951-2016	242.4	64.1	40.8	2.2
	2017	233.0	62.7	42.1	5.3
	Diff	-9.4	-1.4	1.3	3.1
Nov.	1951-2016	56.8	46.8	27.2	1.3
	2017	46.0	49.0	25.3	0.2
	Diff	-10.8	2.2	-1.9	-1.1
Totals	1951-2016	3075.3	72.5	50.5	23.1
	2017	3104.0	72.6	50.7	26.3
	Diff	28.7	0.1	0.2	+3.2

Graph A1. Average Growing Degree Units for 2017 Growing Season in Castana, IA



Graph A2. Temperature for 2017 Growing Season in Castana, IA



Graph A3. Rainfall for 2017 Growing Season in Castana, IA

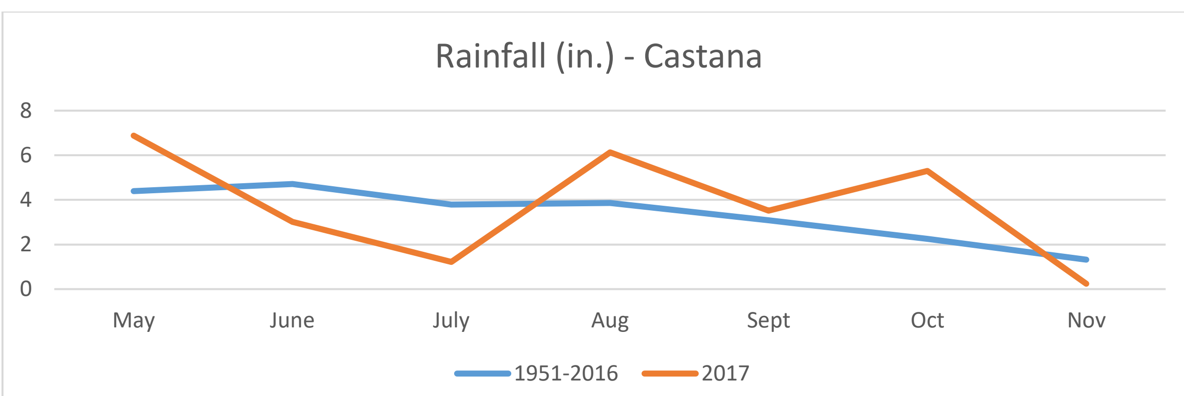
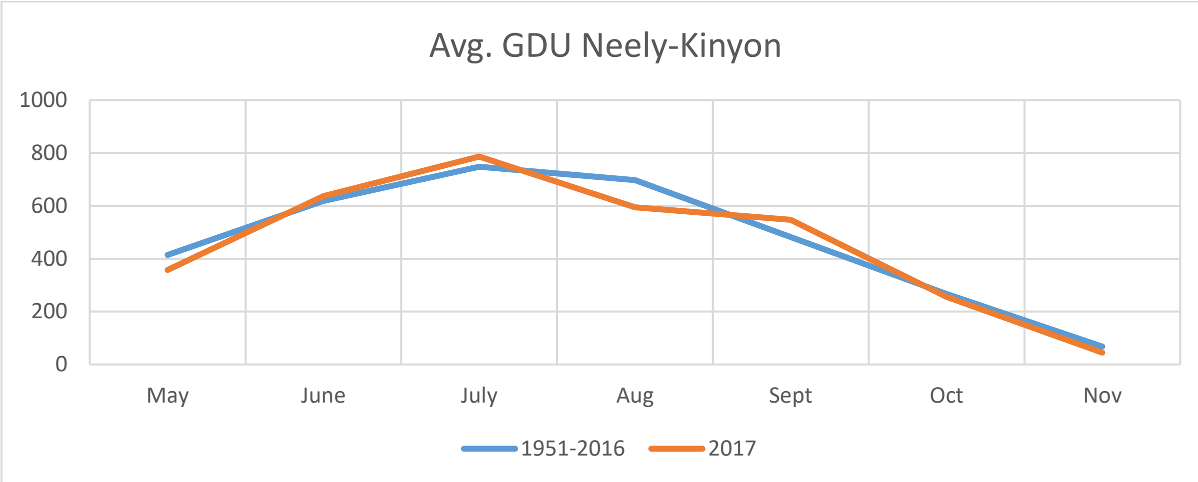


Table A5. Weather Data – Neely-Kinyon Research Farm

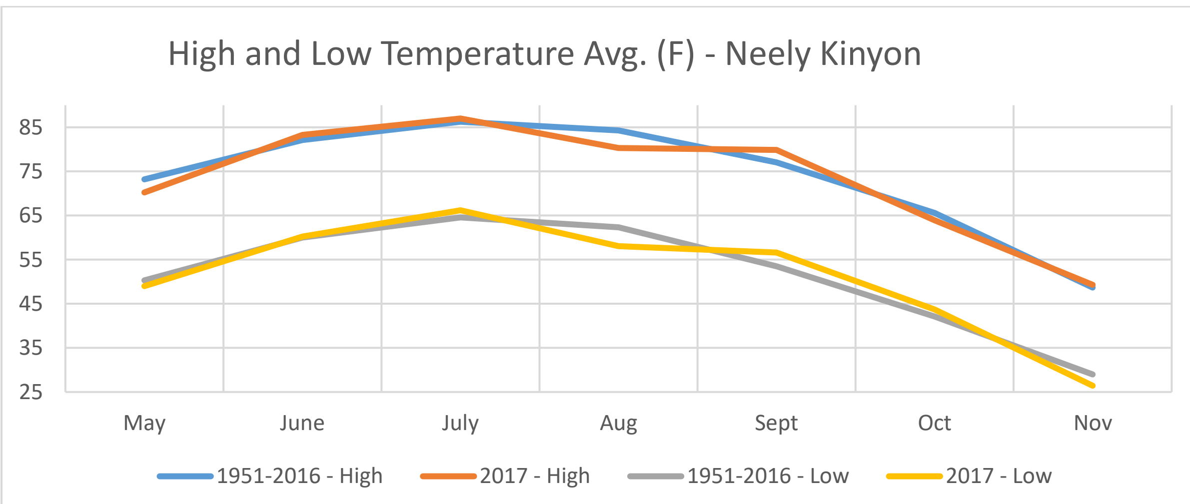
Greenfield

	Time	Avg. Total GDU	Avg. High (F)	Avg. Low (F)	Rainfall (in.)
May	1951-2016	414.0	73.2	50.3	4.5
	2017	358.0	70.3	49.0	6.2
	Diff	-56.0	-3.0	-1.3	1.7
June	1951-2016	618.4	82.1	60.0	4.7
	2017	636.5	83.3	60.3	3.7
	Diff	18.1	1.2	0.3	-1.0
July	1951-2016	748.1	86.3	64.6	4.2
	2017	786.5	87.0	66.2	0.7
	Diff	38.4	0.7	1.6	-3.5
Aug	1951-2016	697.8	84.3	62.3	4.0
	2017	595.0	80.3	58.1	5.1
	Diff	-102.8	-4.0	-4.3	1.1
Sept.	1951-2016	482.7	77.1	53.5	3.8
	2017	547.5	79.9	56.6	4.5
	Diff	64.8	2.8	3.1	0.7
Oct.	1951-2016	266.4	65.6	42.1	2.4
	2017	255.5	64.0	43.7	6.9
	Diff	-10.9	-1.6	1.6	4.5
Nov.	1951-2016	67.7	48.7	29.0	1.8
	2017	45.0	49.3	26.4	0.4
	Diff	-22.7	0.6	-2.6	-1.5
Totals	1951-2016	3251.5	73.9	51.7	25.1
	2017	3224.0	73.5	51.5	27.4
	Diff	-27.5	-0.4	-0.2	+2.3

Graph A4. Average Growing Degree Units for 2017 Growing Season in Greenfield, IA, NK Farm



Graph A5. Temperature for 2017 Growing Season in Greenfield, IA, NK Farm



Graph A6. Rainfall for 2017 Growing Season in Greenfield, IA, NK Farm

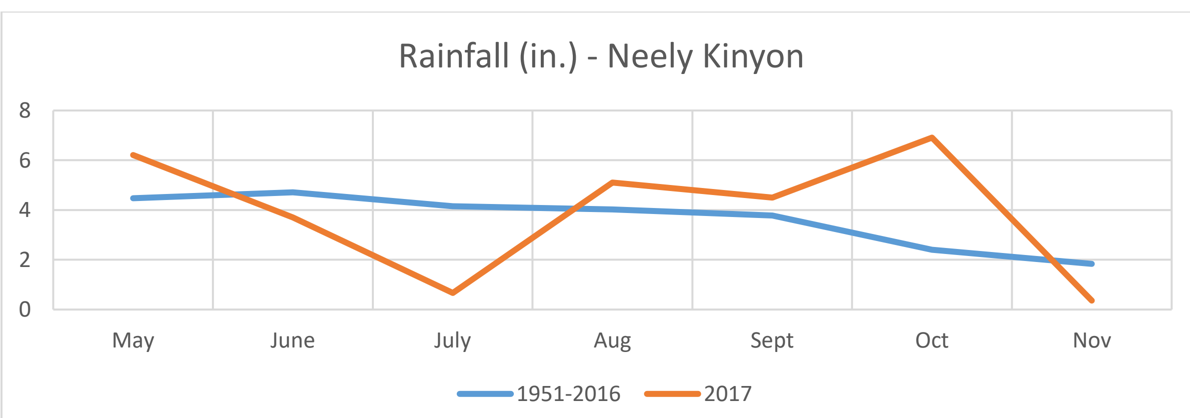


Table A6. JMP model for analysis of variance.

Model	
Effects (Means)	Degrees of Freedom
Location	1
Management (CC vs. NCC)	1
Hybrid	11
Hybrid x Managment	11
Stand	1
Analysis of Variance	
Model	25
Error	22
Total	47

Table A7: Corn grain quality characteristics determined by near infrared spectrometry for 12 hybrids and reported as 100% dry matter basis. Hybrid pedigrees reference in Table A3.

Hybrid	Moisture %	Protein %	Oil %	Starch %	Density g/cm^3
1	16.8 cd	10.73 a	4.80 a	69.42 e	1.31 de
2	14.8 g	10.17 abc	4.50 bc	70.50 cd	1.33 ab
3	15.7 efg	10.23 abc	4.30 de	70.70 cd	1.32 cde
4	17.5 bc	10.26 abc	4.64 ab	70.31 cd	1.32 bc
5	15.4 fg	10.23 abc	4.21 e	71.01 c	1.33 ab
6	17.4 bc	10.6 ab	4.84 a	70.09 de	1.34 a
7	17.8 b	8.77 d	4.39 cd	71.86 ab	1.31 e
8	16.2 def	10.14 abc	4.23 de	70.89 cd	1.32 cde
9	17.0 bcd	9.65 cd	4.41 cd	71.21 bc	1.31 e
10	16.5 cde	9.51 cd	3.74 f	72.40 a	1.30 f
11	19.1 a	9.73 bc	4.60 b	70.86 cd	1.32 cd
12	15.6 efg	9.98 abc	4.36 cde	70.89 cd	1.32 cde
Management					
Cover Crop	16.9 a	9.85 b	4.41 a	71.06 a	1.32 b
No Cover crop	16.1 b	10.10 a	4.39 a	69.54 b	1.30 a
Significance					
Hybrid (H)	<0.001	0.011	<0.001	<0.001	<0.001
Management (M)	0.002	0.008	0.158	<0.001	0.017
H × M	0.878	0.754	0.939	0.339	0.156
R-squared	0.903	0.727	0.939	0.849	0.886
Analysis of Variance	<0.001	0.024	<0.001	<0.001	<0.001

Values followed by the same letter within a column are not significantly different at $P < 0.05$

Table A8: Phenotypic characteristics of 12 corn hybrids following a winter rye cover crop. Hybrid pedigrees reference in Table A3.

Hybrid	50% Pollen Shed GDU†	50% Silk GDU†	Plant Height Inch	Ear Height Inch
1	1412 defg	1434 cde	103.9 ef	45 de
2	1373 g	1387 ef	104.1 ef	44 e
3	1371 g	1373 f	107.4 cde	47 cde
4	1400 efg	1423 cde	100.7 f	44 e
5	1394 fg	1419 def	111.3 bc	48 cd
6	1424 cdef	1439 bcde	106.1 def	48 bcde
7	1430 cdef	1458 abcd	108.4 bcde	46 cde
8	1477 ab	1485 ab	116.7 a	55 a
9	1490 a	1501 a	104.8 def	50 bcd
10	1462 abc	1499 a	108.9 bcde	53 ab
11	1437 bcde	1468 abc	112.4 ab	53 ab
12	1444 bcd	1449 abcd	109.2 bcd	49 bc
Management				
Cover Crop	1467 a	1486 a	107 a	48 a
No Cover crop	1385 b	1403 b	108 a	49 a
Significance				
Hybrid (H)	<0.001	<0.001	<0.001	<0.001
Management (M)	<0.001	<0.001	0.246	0.539
H × M	0.831	0.799	0.838	0.979
R-squared	0.909	0.799	0.907	0.769
Analysis of Variance	<0.001	<0.001	<0.001	0.007

† GDU – Growing Degree Days from planting date

Values followed by the same letter within a column are not significantly different at $P < 0.05$

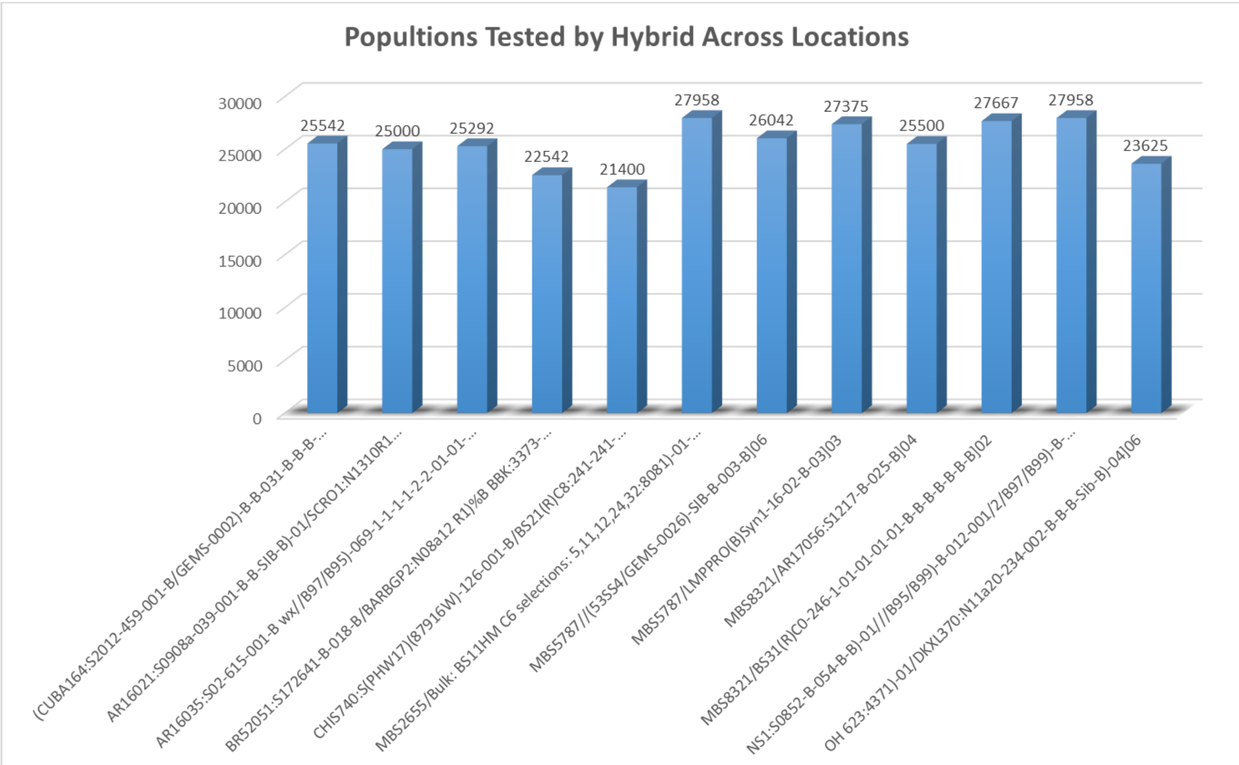
Table A9: Harvest Traits for 12 corn hybrids following winter rye cover crop. Hybrid pedigrees reference in Table A3.

Hybrid	Moisture %	Yield† Bu. Acre^{-1}
1	16.8 bcd	129.4 e
2	14.8 g	157.5 cd
3	16.0 def	151.6 de
4	17.0 bc	153.9 cd
5	15.4 fg	169.5 bcd
6	17.9 ab	178.6 abc
7	17.4 bc	197.4 a
8	16.6 cde	190.9 ab
9	17.8 ab	201.6 a
10	16.7 cde	192.7 ab
11	18.5 a	195.6 a
12	15.7 efg	176 abcd
Management		
Cover Crop	17.0 a	169.7 a
No Cover crop	16.4 b	179.1 a
Significance		
Hybrid (H)	<0.001	<0.001
Management (M)	0.006	0.281
H × M	0.883	0.695
R-squared	0.899	0.792
Analysis of Variance	<0.001	0.003

† Corn grain yield reported at 15.5% moisture

Values followed by the same letter within a column are not significantly different at *P* < 0.05

Table A10. Final harvest population for 12 corn hybrids across winter rye cover crop treatments.



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